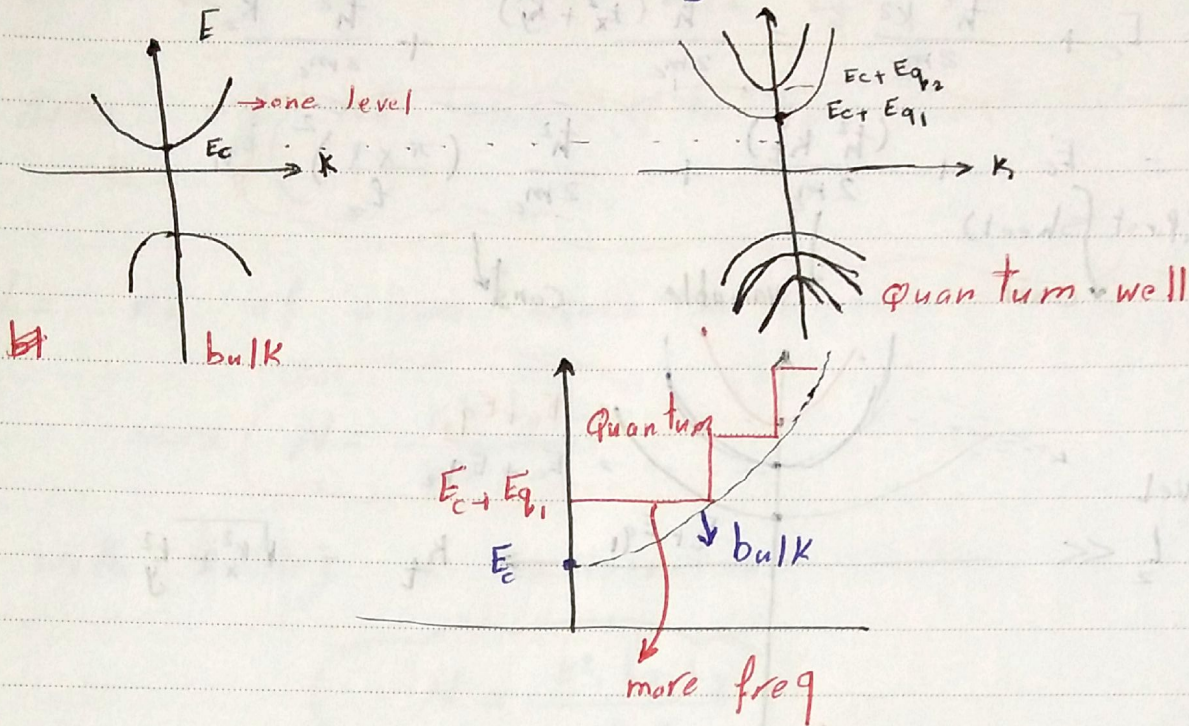


difference between bulk & quantum:



Lec (8)

Bulk material:

$$p_c(E) = \frac{1}{2\pi^2} \left(\frac{2m_c}{\hbar^2} \right)^{3/2} (E - E_c)^{1/2}$$

$$p_v(E) = \frac{1}{2\pi^2} \left(\frac{2m_v}{\hbar^2} \right) (E_v - E)^{1/2}$$

$$n = \int_{E_c}^{\infty} p_c(E) \cdot f(E) \cdot dE$$

Free electron carrier

$f(E)$ = fermi dirac statistical probability function

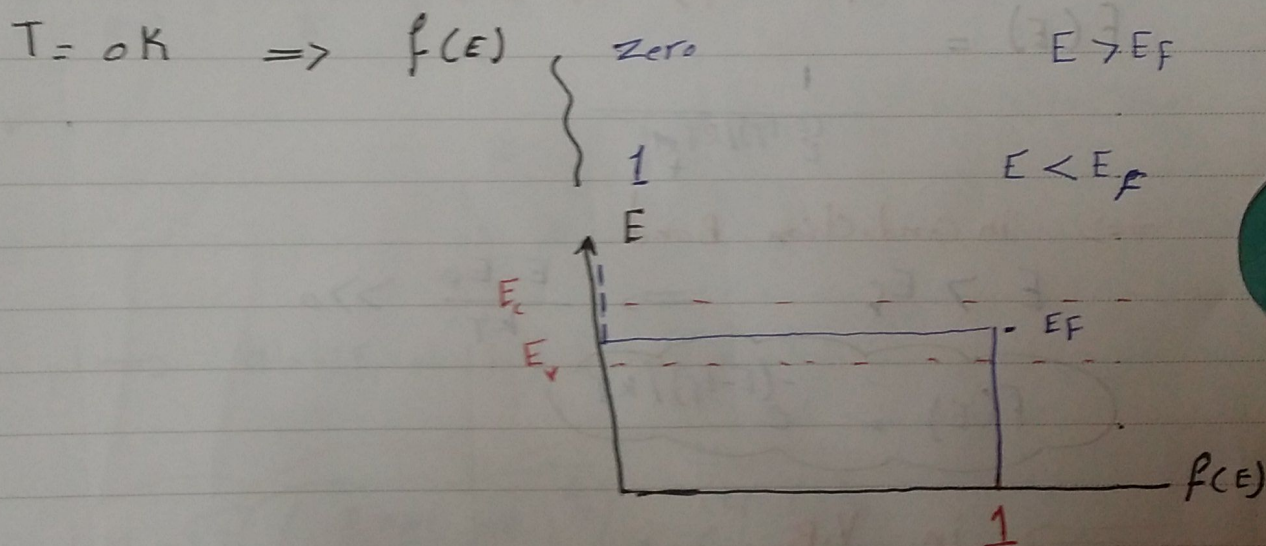
$$f(E) \triangleq \frac{1}{e^{(E-E_F)/KT} + 1}$$

identify the distribution (population) of electron among the allowed energy state as a function of temperature

$f(E=E_a) \triangleq$ probability that the allowed state $(E=E_a)$ is occupied electron

$1 - f(E) \triangleq$ probability that the allowed state $(E=E_a)$ is empty (vacant)

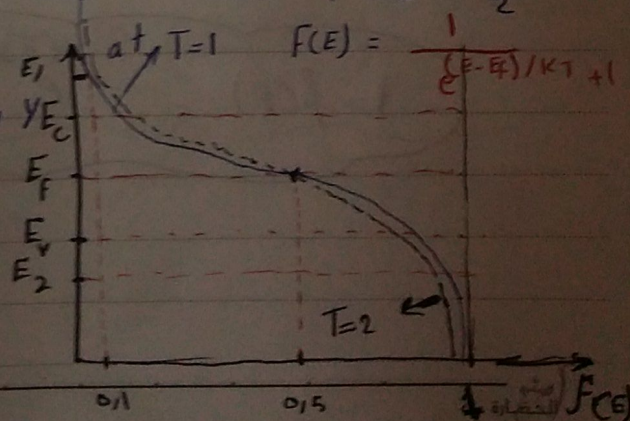
at



At any arbitrary T

$f(E=E_F) = \frac{1}{2}$ energy level where $f(E) = \frac{1}{2}$

$E_F \triangleq$ fermi level energy



$$f(E=E_1) = 0,1$$

$$f(E=E_2) = 0,9$$

$1 - f(E=E_2) = 0,1 \cong$ probability of hole at $E=E_2$ in V.B only

n. of carrier at equilibrium (thermal effect only):

$$n = \int_{E_c}^{\infty} g_c(E) \cdot f(E) \cdot dE$$

- with Boltzman approximation:

$$(E - E_f) \gg kT$$

$$f(E) =$$

$$\frac{1}{e^{(E-E_f)/kT} + 1}$$

$\Rightarrow$ in conduction Band

$$E > E_f$$

$$\Rightarrow \frac{E - E_f}{kT} \gg 0$$

$$f(E) = e^{-(E-E_f)/kT}$$

$\Rightarrow$ in V.B

Carrier = hole $\leftarrow$

$$1 - f(E) = 1 - \frac{1}{e^{(E-E_f)/kT} + 1} =$$

$$\frac{e^{(E-E_f)/kT}}{1 + e^{(E-E_f)/kT}}$$

$$1 - f(E) = e^{(E-E_f)/kT}$$

$$n = \int_{E_c}^{\infty} \frac{1}{2\pi^2} \cdot \left(\frac{2m_c}{h^2}\right)^{3/2} \cdot (E - E_c)^{1/2} \cdot e^{-(E - E_f)/kT} \cdot dE$$

$$n = \frac{1}{2\pi^2} \cdot \left(\frac{2m_c}{h^2}\right)^{3/2} \cdot e^{\frac{-E_f + E_f}{kT}} \cdot \int_{E_c}^{\infty} (E - E_c)^{1/2} \cdot e^{-(E - E_c)/kT} \cdot dE$$

assume

$$* (E - E_c) = X \cdot kT \Rightarrow X = \frac{E - E_c}{kT}$$

$$\Rightarrow dE = kT dx$$

$$n = \frac{1}{2\pi^2} \left(\frac{2m_c kT}{h^2}\right)^{3/2} \cdot e^{(E_f - E_c)/kT} \int_0^{\infty} x^{1/2} \cdot e^{-x} \cdot dx$$

$$\int_0^{\infty} x^{a-1} \cdot e^{-x} \cdot dx = \Gamma(a)$$

$$\Rightarrow a = 1.5 \quad \Gamma(1.5) = \frac{\sqrt{\pi}}{2}$$

$$\Rightarrow n = 2 \left(\frac{2\pi m_c kT}{h^2}\right)^{3/2} \cdot e^{(E_f - E_c)/kT}$$

Free electron N_c

$$p = \int_{-\infty}^{E_v} p_v (1 - f(E)) dE = 2 \cdot \left(\frac{2\pi m_v kT}{h^2}\right)^{3/2} e^{(E_v - E_f)/kT}$$

Free hole N_v

intrinsic Semiconductor ($n=p$):

$$n = p$$

$$\Rightarrow N_c e^{(E_f - E_c)/KT} = N_v e^{(E_v - E_f)/KT}$$

$$(m_c)^{3/2} e^{(2E_c - E_c - E_f)/KT} = (m_v)^{3/2}$$

$$E_f = \frac{(E_c + E_v)}{2} + \frac{3}{4} \frac{KT}{e} \ln \frac{m_v}{m_c}$$

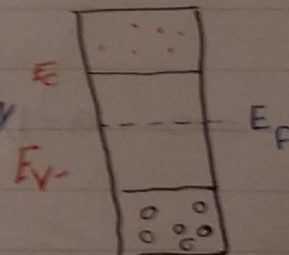
$\downarrow \approx 0$

GaAs

$$m_c = 0.067 m_0$$

$$m_v = 0.45 m_0$$

Fermi level = average of Carrier Energy



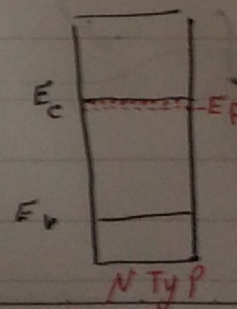
EXtrinsic materials:

n-Type

$$N_D = n = N_c e^{(E_f - E_c)/KT}$$

$$E_f = E_c + KT \ln \frac{N_D}{N_c}$$

≈ 0



الحالة

ex: for Si

$$m_c = 0,98 m_0, \quad m_v = 0,49 m_0$$

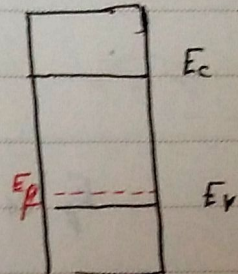
$$N_D = 10^{10} / \text{cc}$$

for P-Type $(E_F - E_v) / kT$

$$N_A = P = N_v \cdot e$$

$$E_F = E_v + kT \cdot \left(\ln \frac{N_A}{N_v} \right)$$

$\downarrow$
 $= 0$



intrinsic carrier concentration:

$$n_i = p = n$$

$$n_i^2 = n \cdot p = N_c \cdot N_v \cdot e^{-\frac{(E_c - E_v)}{kT}}$$

$$n_i = \sqrt{N_c / N_v} \cdot e^{-\frac{E_g}{2kT}}$$

EX:

AT $300 K^\circ$ the energies of the bandgap edges & fermi level for particular semiconductor ($m_c = m_v$) are given below:

$$E_c = -4,2 \text{ eV}$$

$$E_v = -6 \text{ eV}$$

$$E_f = -5,2 \text{ eV}$$

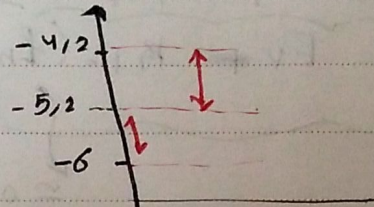
Determine:

- 1) the material n type OR ptype Given reson
- Probability of occupation at energy level $E = E_c$

Sol:

1)-

P-Type E_f is closer to V_B Than C.B



2)-

$$f(E) = \frac{1}{e^{(E-E_f)/kT} + 1}$$

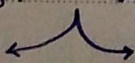
$$f(E) \Big|_{E=E_c} = \frac{1}{e^{(-4.2+5.2)/kT} + 1} = \frac{1}{e^{1/0.025} + 1}$$

~ Lec (9) ~

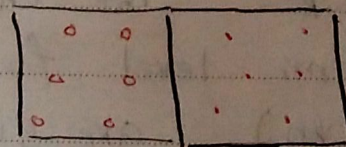
P_n junction:

Draw band diagram at:

- 1) Not equilibrium
- 2) At thermal
- 3) At quasi

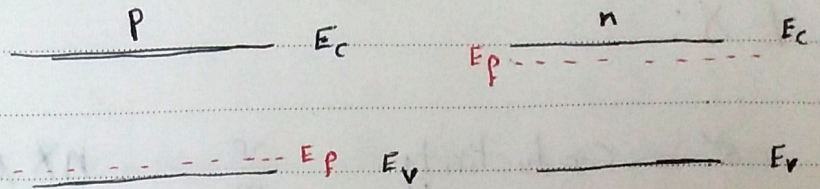


P-type n-type

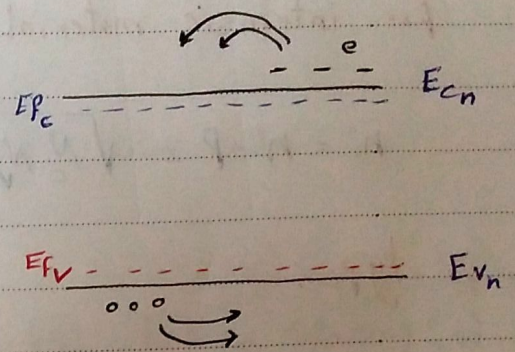
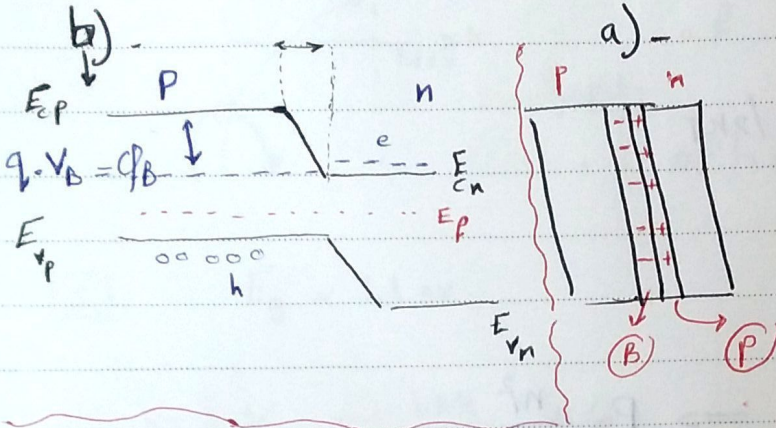


FB DC Biasing R.B

SOL:



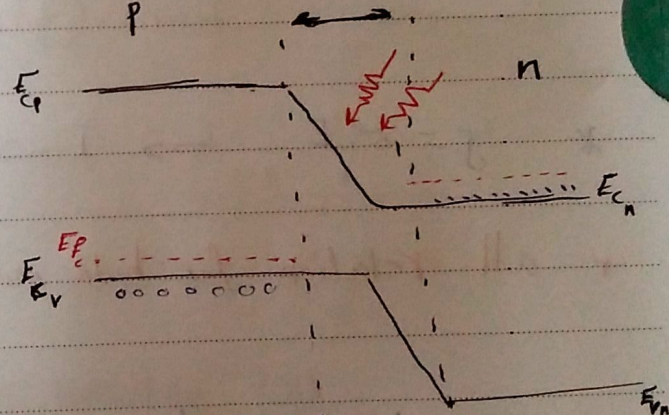
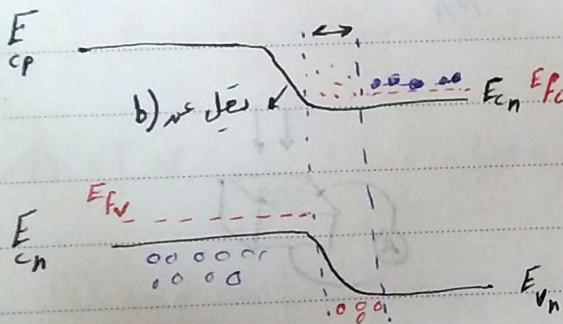
depletion layer



c)

F.B

R.B



Quazi fermi level

$$E_{F_c} > E_{F_v}$$

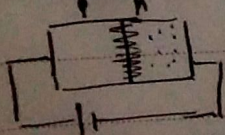
$$E_{F_c} - E_{F_v} > 0$$

$$E_{F_c} - E_{F_v} < 0$$

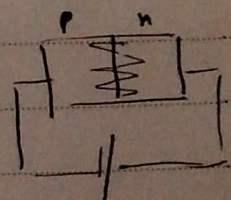
=> optical source

(release high energy)

Recombination



optical sensor



الخطوة

EX:

$$\sigma = \text{conductivity} \quad \frac{\sigma}{m} = n \times \mu_e \times q + p \times \mu_v \times q$$

for intrinsic material

$$n_i = n = p = \sqrt{N_c N_v} \cdot e^{-E_g/2kT}$$

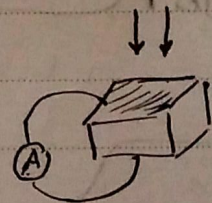
N-type:

$$n_i^2 = n \cdot p \quad \text{---} \quad n = N_D \quad \Rightarrow \quad p = \frac{n_i^2}{N_D}$$

P-Type:

$$n_i^2 = n \cdot p \quad p = N_A \quad \Rightarrow \quad n = \frac{n_i^2}{N_A}$$

$$* \quad J = \sigma \cdot E \quad \Rightarrow \quad I = \sigma \cdot E \cdot A$$



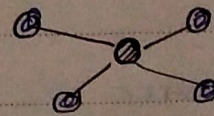
* all relation for bulk material

Semiconductors:

1) - elemental semiconductor:

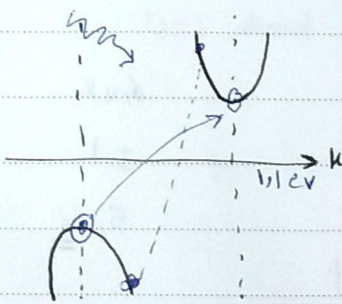
IV material

ex Si, Ge, Sn, C



EX. For Si:

III indirect bandgap



⇒ Recombination Process non radiative
≡ energy released is on the form of heat

APP:

optical sensor/ Solar cell

[2] $E_g = 1.1 \text{ eV}$

$\lambda_g = \frac{1.24}{E_g (\text{eV})} \mu(\text{m})$
cutoff λ

Si $\Rightarrow$ 1100 nm

[3] Lattice Spacing (a)

$a = 0.357 \text{ nm}$

2) Binary (Compound Semi conductor):

1) IV, V AS EX: SiC

II indirect Energy bandgap

[2] $E_g = 2.42 \text{ eV}$

$\lambda_g = \frac{1.24}{2.42} = 512 \text{ nm}$

Visible Light

[3] $a = 0.357 \text{ nm}$

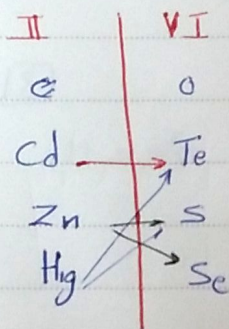
APP: As humidity detector

2) III V

III	V
Al	N
Ga	P
In	As
	Sb

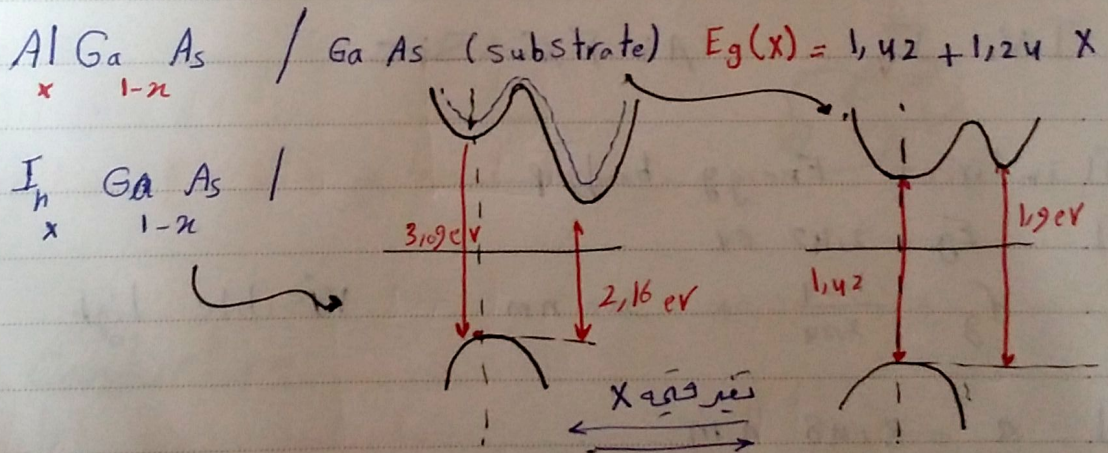
laser source	E_g (ev)	direct/indirect	λ (nm)
EX: — GaAs	1,42	direct	5,65
intrinsic InP	1,35	"	5,81
InAs	0,35	"	
InSb	0,17	"	6,48
— GaN	3,39	—	3,1
AlAs	2,16	indirect	5,66
GaP	2,26	indirect	

3: (II) (VI)

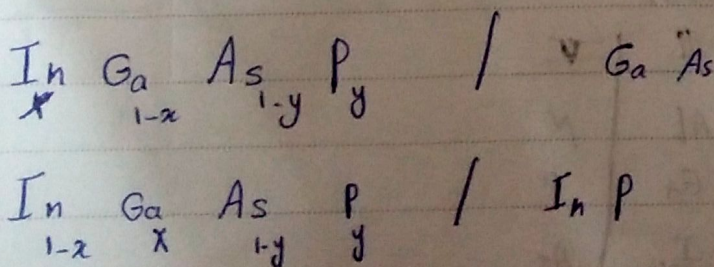


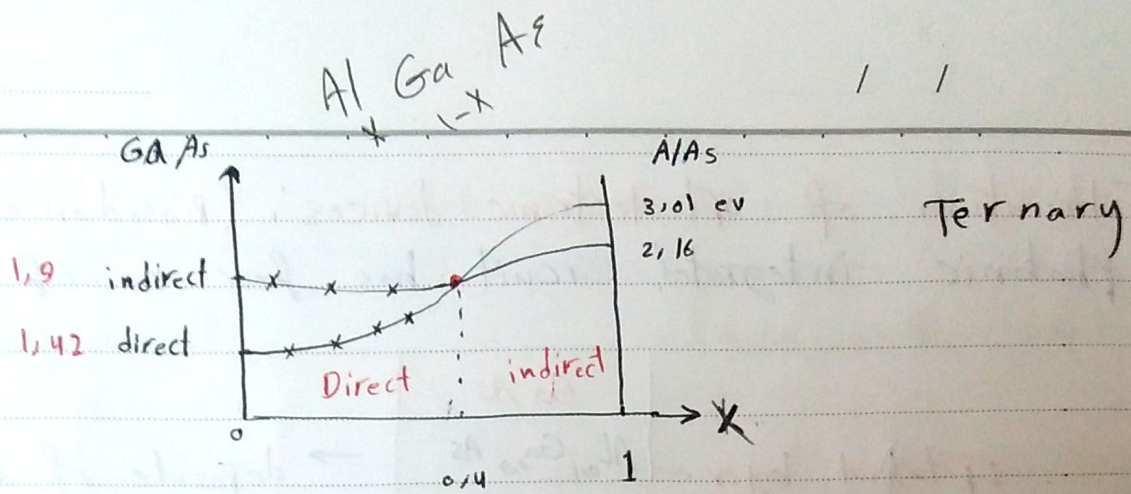
CdTe $E_g = 1,5$ eV
 Voltaic solar cell
 Photo

3) - Alloys (Ternary) :



4) - Alloys (Quaternary)





al lec (10)

Alloying

- substitutional element is taken from the same group

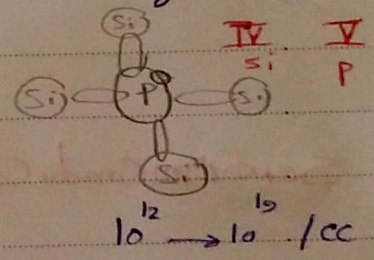
- $10^{22} / \text{cc}$

- modification of E_g (change cut off freq)

- modify type (D/I)
- modify lattice constant
- this: obtain lattice matched Hetero structure

Doping

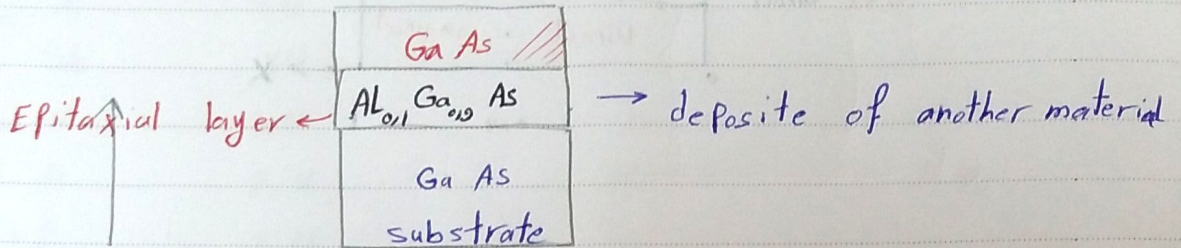
- substitutional element from adjacent group



increase conductivity

$$\sigma = nq\mu_c + pq\mu_v$$

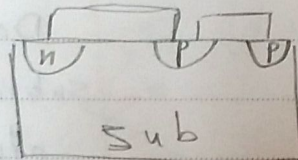
Fabrication of optoelectronic devices: (Based on epitaxial layer)
 Photonic integrated circuit has few no. of component



electronic device

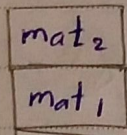
1) epitaxial

2) Diffusion



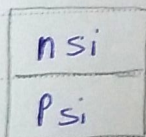
semiconductor junctions

* junction (interface between 2 material)



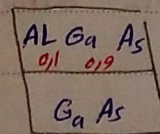
Junction

Homo junction



junction between 2 semiconductor material with the same E_g

Hetero junction



$$E_g(x) = 1.424 + 1.247 \cdot x$$

if $x < 0.45$

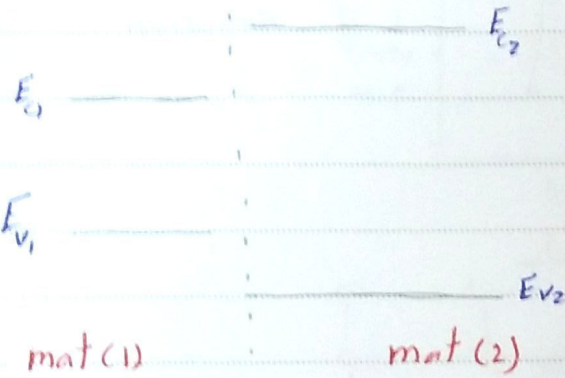
$$E_g(x) = 1.424 + 1.247x + 1.147(x - 0.45)^2$$

$$0.45 < x < 1$$

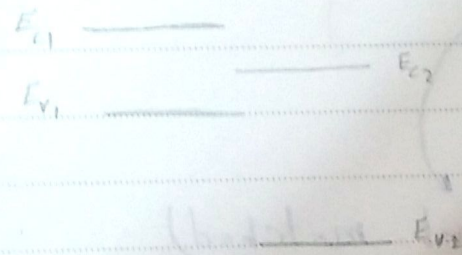
Hetro junction

Band gap alignment

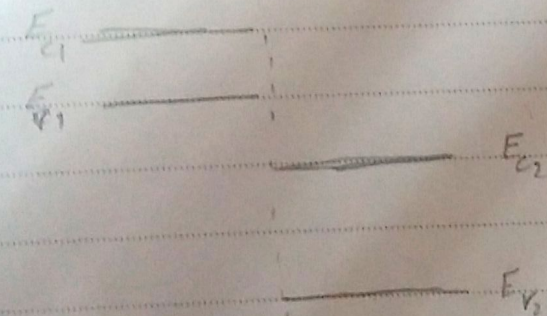
1) straddling jun



2) staggered jun



3) broken-gap jun



Hetro junction Type

isotype

AlGaAs-N	P-AlGaAs
n-GaAs	P-GaAs

$$E_{g1} < E_{g2}$$

n N

Anisotype

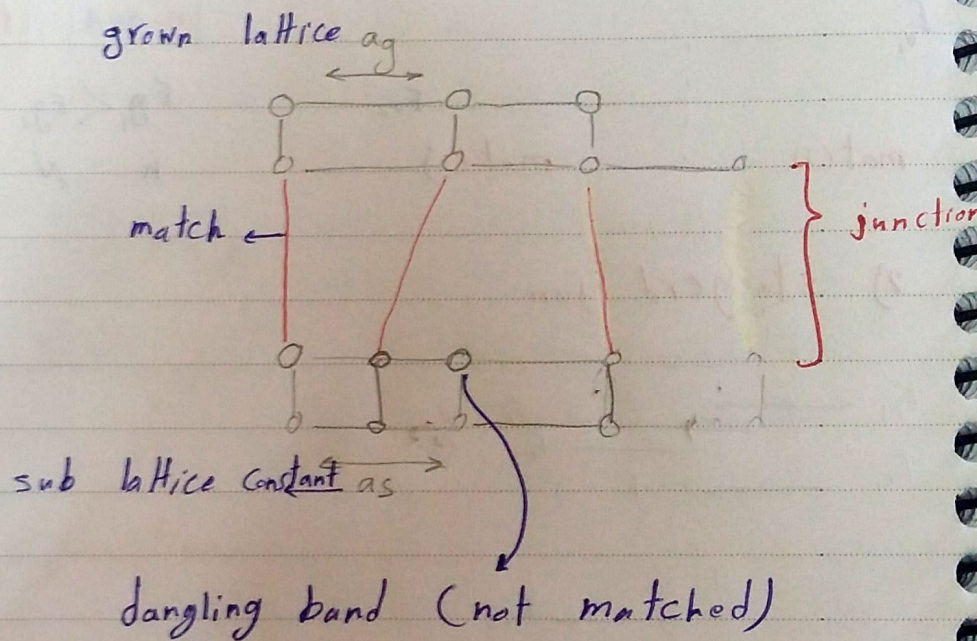
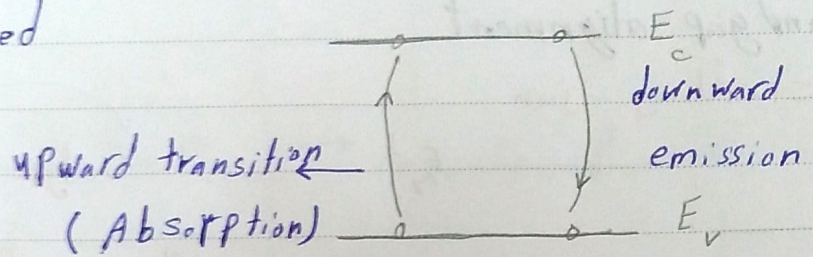
P-AlGaAs	n-GaAs
----------	--------

P_n

N-AlGaAs	P-GaAs
----------	--------

N_p

Radiative transition:
all epitaxial layer
must be lattice matched



Not matched cause
trap states Band diagram:

